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# TECHNOLOGICAL CHOICE UNDER ENVIRONMENTALISTS' PARTICIPATION IN EMISSIONS TRADING SYSTEMS


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**Abstract**

We model competition in an emissions trading system (ETS) as a game between two firms and environmental group. In a previous stage, firms endogenously choose their manufacturing technologies. Our results show that there is a U-shape relationship between how polluting the chosen technology is and the degree of the environmentalists' impure altruism. Firms choose a more polluting technology in the presence of the environmentalists than in their absence if they are characterised by high enough degrees of impure altruism.



Keywords: Emissions Trading Systems; Technology Choice; Induced Technological Change; Impure Altruism

JEL Codes: L13 Q30 O31

# 1 Introduction

Emissions trading systems (ETS henceforth) are market based instruments used to control pollution. The idea of the ETSs or permits markets has its origins in Coase (1960) and Dales (1967) and relies upon the creation of economic incentives to reduce pollution through the exchange of permits. Following the Kyoto Protocol (1998) ETSs have become major tools in the anti-pollution policy in a number of countries.[1]

Interestingly, several legal frameworks opened up the participation in the Emissions Trading System not only to firms but also to third parties, such as citizens, consumers, environmental organizations, etc. This right to participate is contemplated, for example, in the United Nations' Framework Convention for Climate Change (Guidelines FCCP/ CP/ 2001/ 2/ Add.4) and in the EU's Directive 2003/87/EC. Similarly, in the US, third parties can participate in the Sulphur Allowance Trading Program (SAT) and in the Clean Air Incentives Scheme (RECLAM). Groups such as the Acid Retirement Fund and the Clean Air Conservancy Trust in the US or Sandbag in the UK are examples of NGOs who use their funds (mainly collected through charitable donations) to purchase permits from ETSs. By withdrawing permits from the market, this type of organisations aim at increasing the price of polluting and therefore at inducing firms to invest in technologies to reduce their emissions.[2]

Some theoretical contributions have studied the reasons why third parties should be allowed to participate in ETSs (Smith and Yates, 2003a, 2003b; Shrestha, 1998). Generally, it is argued that the participation by third parties gives valuable information to the regulator regarding the market equilibrium

[1] For example, in the US, there are ETSs in place for the reduction of SOx and NOx emissions. Also, the European Union (EU) has implemented an ETS for the reduction of $CO_2$. This is the largest application of ETS in geographic terms (Newbery, 2008).

[2] For example, this objective is very clearly stated in the Acid Rain Retirement Fund's ethos.

when the regulator faces uncertainty.[3] Interestingly, the academic literature has already provided empirical evidence on the presence of the thirds in ETS and its effects (see Schwarze and Zapfel, 2000; Israel, 2007; and Joskow et al. 1998).

Despite the relevance of the issue, the literature on ETS and technology choice has largely overlooked the implications of third parties' participation for firms' technological choices. However, a related literature strand has explored the linkages between the existence of policies against climate change and the degree of technological change. For example, Newell et al. (1999) and Popp (2002) analyze how higher energy prices induce a higher technological innovation.[4] Some other contributions have compared the propensity to technological innovation generated by several market-based instruments (Fischer et al., 2003; Requate and Unold, 2003; and Kerr and Newell, 2003), reaching mixed conclusions.

The objective of our paper is to study the interaction of firms and environmental groups in ETS and the implications of this for firms' technological choices. We introduce an oligopsony which must purchase permits in an ETS. Firms can choose the type of production technology they will use. The technologies available to firms differ in their environmental credentials: The more polluting the production techology is, the more permits the firm requires per unit of output. We allow an environmental group to purchase (and therefore withdraw) permits from the market. The price of the permits will depend on the aggregation of the firms' and the environmentalists' demand of permits. Therefore, the participation of the environmentalists affects the price of the

[3] For some other references showing the advantages of allowing citizens to take part in the ETS can be found in English and Yates (2007) and Rousse (2008) and Eshel and Sexton (2009). Malueg and Yates (2006) also show that the citizens may prefer to participate in the permits' market under a grandfathered system instead of lobbying the regulator to reduce the total number of allocated permits.

[4] See also Chakravorty et al. (1997). On the other hand, Goulder and Schneider (1999) and Goulder and Mathai (2000) examine the implications of Induced Technological Change (ITC) for $CO_2$ abatement policy.

permits and the incentives to adopt a less polluting technology.

In the spirit of Andreoni (1989, 1990) we assume that the members of the group gain a non-material utility from withdrawing permits.[5] Andreoni (1989, 1990) highlights that people are impurely altruistic, as they obtain some gains in utility (warm glow) from charitable giving. Interestingly, there is ample experimental evidence of impure altruism in public good games (see for example Palfrey and Prisbey, 1996, 1997, and Goeree, Holt and Laury, 2002). In our paper, we assume that the environmentalists act partly driven by the warm glow. This "impurely altruistic" behavior introduces a distortion in the market. We will study how the emission levels and technological choice are affected by the environmentalists' presence in the ETS and their degree of impure altruism and will compare the equilibrium outcomes with and without their participation.

Our results show that there is a U-shape relationship between how polluting the chosen technology is and the degree of the environmentalists' impure altruism. Moreover, we show that firms tend to choose a more polluting technology in the presence of the environmentalists in the ETS than in their absence if the environmentalists are characterised by high degrees of impure altruism. Although higher degrees of impure altruism can actually induce firms to adopt worse technologies, they can also lead to lower emissions levels through the reduction of output.

The rest of the paper is structured as follows: In section 2 we present our model. In section 3 we analyse the technology choice by firms when the environmentalists do not participate in the ETS. In section 4, we study the case where environmentalists' participation in the ETS. In section 5 we conduct a comparative static analysis regarding technology choices, emissions and output levels in both settings. Section 6 concludes.

[5] We consider members of the group not only the activists but also the donors or contributors to the group.

## 2 The model

In our model, two monopolistic firms act as oligopsonists in the permits' market. Each firm faces a linear inverse demand function such as[6]

$$P_i = a - q_i \tag{1}$$

where $q_i$ is firm i's level of output produced by firm $i$.

Prior to start producing, firms choose their manufacturing technology from a spectrum of available technologies which differ in the level of emissions derived from the production of each unit of output. Firms must buy permits to offset their emissions.[7]

The choice of technology determines the number of permits required to produce each unit of output. We denote the number of permits required per unit of output by $k$ and will use $k$ to index the technologies available to firms. The greener (the more environmentally friendly) the technology is, the lower its associated $k$. The total number of emissions and, as a consequence, the total number of permits demanded by firm $i$ depends on the type of technology (how polluting the technology is) and the level of output chosen by firm $i$

$$y_i = k_i q_i. \tag{2}$$

We assume that the available technologies differ also in the investment required to adopt them

$$F_i = \gamma(1 - k_i)^2. \tag{3}$$

[6] We do not contemplate the case where there is competition in the final market so that to be able to isolate the effect of competition in the permits market.

[7] One interpretation of our model is that the firms are new entrants to the market and they do not receive permits through grandfathering. Alternatively, even with grandfathering, firms may not have enough permits with their initial allocation. In that case, the demand of permits would represent the extra permits needed above the initial allocation.

Our modelling of the technology costs implies that adopting a greener technology entails higher adoption costs than adopting a more polluting one. The innovation costs are assumed to be quadratic to reflect the existence of diminishing returns to investment. For the sake of simplicity, we assume that $k_i \in (0, 1)$.

We assume that firms do not incur in any other production costs than those derived from the acquisition of permits, that is

$$C_i(y_i) = R^e y_i. \tag{4}$$

All in all, firms profits can be written as follows

$$\pi_i = P_i q_i - R^e y_i - \gamma(1 - k_i)^2. \tag{5}$$

We assume that there is a third player in the permits market : an environmental group. The environmentalists can withdraw permits from the market by purchasing a number $x$ of permits, thereby affecting the equilibrium price in the permits market. The (aggregate) demand of permits will therefore be the sum of the permits demanded by firm $i$ and $j$ and by the environmentalists $(y_i + y_j + x)$. According to standard properties of demand and supply, we assume that the (equilibrium) price of permits, $R^e$, is increasing in the demand of permits. We define $R^e$ as[8]

$$R^e = c + h(y_i + y_j + x). \tag{6}$$

where we normalise $c$ to 0 and $h$ to 1. Our modelling of the price of permits differs from those contributions which assume that firms are price-takers and also from those contributions, such as Boyd and Conley (1997) and Conley and Smith (2005), where citizens can buy permits at personalized prices.

[8]Note that we are modelling the supply of permits only implicitly. As our main focus is the interaction between the price of the permits and the technological choices of firms, we refrain from going one step backwards and modelling in detail the supply side of the ETS.

We assume that the environmentalists are impurely altruists, that is their behavior is (partly) driven by the maximisation of their own utility. The environmentalists' maximise the utility gained from withdrawing permits ($zx$) minus the externalities ($E$) and the cost of withdrawing permits ($Rx$). The environmental group's objective function ($\Omega$) therefore is:

$$\Omega = -E - R^e x + zx. \tag{7}$$

The last term in $\Omega$ is related to the impure altruism which characterises the environmental group. In our model, the degree of impure altruism is measured by a parameter, $z$, which represents the utility gains experienced by the environmentalists from withdrawing one unit of permits. More generally, the parameter $z$ can be interpreted as the extra weight that the environmentalists give to the reduction of emissions.[9]

We assume that there is one unit of externality produced per each unit of emissions

$$E = \sum_{i=1}^{2} y_i. \tag{8}$$

From now on, we will use the term "emissions" as a synonym of "externalities" or "pollution". The timing of the game is as follows: In the first stage, firms choose their production technologies.[10] In the second stage, the environmentalists purchase permits. In the last stage, firms choose quantities (implicitly determining their demand for permits).[11] We assume that firms choose simultaneously in stages 1 and 3. We solve the game by backwards induction to analyse the Subgame Perfect Nash Equilibrium (SPNE). For

[9] Our model is related to Ahlheim and Schneider (2002), as we also (implicitly) introduce the third parties' preferences in our model. However, in their contribution the third party in the ETS can sell permits.

[10] As technology choices imply a long term commitment, we assume that they take place in the first stage.

[11] Reducing the second and third stages to a single stage where firms and environmentalists take decisions simultaneously does not alter qualitative our results.

comparison purposes, we also solve the model without the environmentalists' participation (that is, $x = 0$ and the game is reduced to stages 1 and 3). We use subscript $_G$ ($_{NG}$) to denote the solutions to the case where the environmentalists are allowed (are not allowed) to participate in the ETS. All proofs to our lemmata and propositions are relegated to the appendix.

# 3 The environmentalists are not allowed to participate in the ETS market

In this section, we solve the game where the environmentalists are excluded from the ETS market. Therefore, $x$ is set to be zero ($x = 0$). In the last stage, firms choose their output levels in order to maximize their profits. The first order condition (FOC henceforth) yields:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2q_i - k_i^2 q_i - k_i(k_i q_i + k_j q_j) = 0. \tag{9}$$

Solving for $q_i$, we obtain firm $i$'s reaction function,

$$q_{i,NG}^R = \frac{a - k_i k_j q_j}{2(1+k_i)^2}. \tag{10}$$

From the reaction functions we can see that although firms do not compete in the final product market, their output levels are negatively related ($\partial q_i^R / \partial q_j = -k_i k_j < 0$ for any $k_i, k_j \in (0,1)$). This implies that firms' decisions on output are strategic substitute. Furthermore, the more polluting each of the firms' manufacturing technologies are (that is, the higher $k_i$ and $k_j$ are), the stronger that relationship is. In fact, their output levels are not independent from each other's because the price of permits (which affects firms' marginal cost of production) depends on both firms' demand for permits, which, in turn depend on their respective output levels and technological choices.

Solving the system of reaction functions, we obtain the equilibrium level of output[12]

$$q_{i,NG}^{*}=\frac{a(2-k_ik_j+2k_j^2)}{4(1+k_j^2)+k_i^2(4+3k_j^2)}. \tag{11}$$

It is easy to see that the derivative of $q_{i,NG}^{*}$ with respect to $k_i$

$$\frac{\partial q_{i,NG}^{*}}{\partial k_i}=\frac{-a(k_j(4(1+k_j^2)+k_i^2(4+3k_j^2))+2k_i(4+3k_j^2)((2-k_ik_j+2k_j^2)))}{(4(1+k_j^2)+k_i^2(4+3k_j^2))^2}, \tag{12}$$

is negative for any $k_i, k_j \in (0,1)$. This implies that the more polluting the technology used by firms is, the less they produce. The intuition for this is that as $k_i$ increases, firms require more permits to produce the same level of output. As a consequence, the price of permits rises (due to more permits being demanded). This increases firm $i$'s marginal cost of production, inducing firm $i$ to decrease its output. Our next lemma summarises our first result.

**Lemma 1** $q_{i,NG}^{*}$ *is decreasing in* $k_i$.

Substituting $q_{i,NG}^{*}$ and $q_{j,NG}^{*}$ into firms' profit maximising and rearranging yields

$$\pi_i(q_{i,NG}^{*})=(1+k_i^2)(q_{i,NG}^{*})^2-\gamma(1-k_i)^2. \tag{13}$$

In the first stage, firms choose $k_i$ to maximise their profits. The first order condition yields

[12] The second order conditions (SOCs henceforth) for a maximum are fulfilled.

$$\frac{\partial \pi_i}{\partial k_i} = 2k_i(q_{i,NG}^*)^2 + 2(q_{i,NG}^*)\frac{\partial q_{i,NG}^*}{\partial k_i}(1+k_i^2) + 2\gamma(1-k_i) = 0. \qquad (14)$$

Using the implicit function theorem we can characterise the relationship between the equilibrium $k$ in symmetry, $k_{NG}^*$, and the parameters of the model, $a$ and $\gamma$. Our finding is the following[13]:

**Proposition 1:** $k_{NG}^*$ *is increasing in* $\gamma$ *and decreasing in* $a$.

In other words, the higher $\gamma$ and the lower $a$, the more polluting firms' technology will be in the absence of the environmentalists from the ETS. Both $a$ and $\gamma$ are related to the profitability of the investment in technology. Although the parameter $\gamma$ is invariant with the technology choice, it magnifies the differences between the costs of adopting a clean or a polluting technology. Essentially $\gamma$ scales up the differences in the technology costs. As a consequence, the higher $\gamma$, the more expensive "cleaner" (lower $k$) technologies are relative to "more polluting" (higher $k$) ones.

The parameter $a$ is related to the market size and therefore to the profitability (other things being equal) of investing in a "greener" technology. Higher market sizes (higher $a$) will lead to higher output levels (other things being equal). This, in turn, will lead to higher demand of permits and therefore higher permit prices. Given this, firms have a stronger incentive to invest in a "greener" technology in larger markets.

[13] The SOC for a maximum holds for any $k \in (0,1)$ for $\gamma > 0.08601a^2$. We assume that $\gamma$ and $a$ take values that fulfill this inequality so that to guaranee the existence of interior solutions.

# 4 The environmentalists are allowed to participate in the ETS market.

In this section, we solve the game where the environmentalists can participate in the ETS. In the last stage, firms choose their output levels in order to maximize their profits. The first order condition yields:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2q_i - k_i^2 q_i - k_i(k_i q_i + k_j q_j + x) = 0. \tag{15}$$

Solving for $q_i$, we obtain the firm $i$'s reaction function

$$q_{i,G}^R = \frac{a - k_i k_j q_j - k_i x}{2(1 + k_i)^2}. \tag{16}$$

As in the case without the environmentalists' participation in the ETS, firms' outputs are strategic substitutes, even in the absence of competition in the product market. As before, the more polluting each of the firms' manufacturing technologies are (that is, the higher $k_i$ and $k_j$ are), the stronger that strategic substitutability between their outputs. Furthermore, firm $i$'s output and the number of permits withdrawn by the environmentalists are also strategic substitutes. This relationship is stronger, the more polluting the technology chosen by firm $i$ is.

Solving the system of reaction functions, we obtain the equilibrium level of output[14]

$$q_{i,G}^* = \frac{a(2 - k_i k_j + 2k_j^2) - k_i(2 + k_j^2)x}{4(1 + k_j^2) + k_i^2(4 + 3k_j^2)}. \tag{17}$$

Substituting $q_{i,G}^*$ into the environmentalists' objective function and rearranging yields

[14] The SOCs for a maximum are fulfilled.

$$\Omega = -\sum_{i=1}^{2}(k_i q^*_{i,G}) - Rx + zx. \tag{18}$$

The environmentalists choose the number of permits to buy, $x$, in order to maximise their objective function, $\Omega$. This maximisation problem has a solution $x^*_G(k_i, k_j)$ which is

$$x^*_G = \frac{2(k_j^2 + k_i^2(1+k_j^2)) - a\varphi + z\psi}{2(2+k_i)^2(2+k_j)^2}, \tag{19}$$

where $\varphi = 2k_j + k_i^2 k_j + k_i(2+k_j^2)$ and $\psi = 4(1+k_j)^2 + k_i^2(4+3k_j^2)$.[15] In order to analyse the behavior of the environmentalists, it is sufficient to analyse $x^*_G$ in symmetry, as the two markets and firms are symmetric and they receive the same weight in the environmentalists' objective function (in other words, the environmentalists do not care more about the emissions by one firm or the other). $x^*_G(k_i,k_j)$ evaluated in symmetry ($k_i = k_j = k$) is

$$x^*_G|_{k_i=k_j=k} = \frac{-2ak + 2k^2 + z(2+3k^2)}{2(2+k^2)}. \tag{20}$$

Several interesting observations can be made from $x^*_G$. The following proposition summarises them:

**Proposition 2:** *$x^*_G$ is decreasing in $a$ and increasing in $z$. Furthermore,* $x^*_G > 0$ requires *small enough $a$ and/or large enough $z$.*

Interestingly, the equilibrium number of withdrawn permits is decreasing in $a$. As discussed above, the higher $a$ is (the larger the market), the more profitable investing on a less polluting technology is. Therefore, the higher $a$, the less necessary it is to induce firms to adopt "greener" technologies by making permits more scarce.

[15] The SOC for a maximum are fulfilled.

Furthermore, the number of permits withdrawn by the environmentalists is increasing in $z$. The more impurely altruistic the environmentalists are, the higher weight the withdrawal of permits has relative to the welfare terms in their utility functions, thus, increasing the number of permits withdrawn in equilibrium.

Finally, for relatively large values of $a$ and/or relatively low values of $z$, the environmentalists would not participate in the ETS, as $x_G^* \leq 0$.That is, the environmentalists choose not to withdraw any permits in those circumstances. This may constitute another explanation for Israel (2007)'s observation that the environmentalists have not been participating very intensively in ETSs: Non-participation might be the result of the environmentalists' optimization problem, a voluntary decision of excluding themselves from the ETS.

Before solving the first stage, it is interesting to conduct some comparative statics regarding the effect of the technology choice on the level of output when the environmentalists are present in the ETS. This will allow us to fomulate lemma 2, which is the counterpart to lemma 1 for the case without the environmentalists' participation. Substituting $x_G^*$ into $q_{i,G}^*$ and analyzing $q_{i,G}^*$, we can state the following:

**Lemma 2** $q_{i,G}^*$ *is decreasing in* $k_i$*.*

In other words, as in the case without the environmentalists, there a negative relationship between how polluting the production technology is and the level of output in equilibrium.

Now we proceed to solve the first stage where firms choose technologies to maximise profits. Substituting (19) into (17) and the latter into the profit function and applying the FOC for maximisation yields

$$\frac{\partial \pi_{i,G}}{\partial k_i} = 2k_i(q_{i,G}^*)^2 + 2(q_{i,G}^*)\frac{\partial q_{i,G}^*}{\partial k_i}(1 + k_i^2) + 2\gamma(1 - k_i) = 0. \qquad (21)$$

Unfortunately, the closed-form solution for the first order condition is again very intrincate, therefore we resort to the implicit function theorem to characterise the relationship between the equilibrium $k$ and $z$. Focusing on the symmetric case and on the combinations of parameters where the SOCs hold, we can state the following:

**Proposition 3:** *There is a critical value of $z$, $z_{cv}$, above (below) which $k_G^*(z)$ is decreasing (increasing) in $z$. The critical value of $z$ is increasing in $a$.*

In other words, proposition 3 states that there is a U-shape relationship between how polluting the chosen technologies are and the degree of impure altruism in the symmetric equilibrium. As $z$ increases, firms will tend to invest in technologies that are less polluting (lower $k$) up until a critical point of $z$, where increases in $z$ will actually lead to investments in more polluting technologies. The intuition behind this result is the following: As $z$ increases, the environmentalists tend to withdraw more permits from the market. This has two effects: First, firms tend to choose cleaner technologies, as the marginal cost of producing is higher due to the lower number of permits which are required per unit of output. Second, firms reduce their output levels (note that $q_i^*$ is decreasing in $x$). As firms reduce their production levels, the investment in cleaner technologies becomes less profitable. The interaction between these two effects will determine the technology choice. For low levels of $z$, the first effect dominates the second effect. However, for high levels of $z$, the second effect dominates. Proposition 3 also states that $z_{cv}$ is increasing in $a$. In other words, larger market sizes make the second effect above (reduction of output) less likely to outweight the first effect (technology substitution).[16]

[16] Furthermore, it can be easily shown that $\gamma$ plays the same role as in the case without the environmentalists participation, that is, $k_G^*$ is increasing in $\gamma$.

# 5 Comparative Analysis

In this section we compare the equilibrium outcomes (technology choices, levels of output and emissions by firms $i$ and $j$) across the two cases solved above, namely the ETS without the environmentalists' participation and the ETS with the environmentalists' participation.

## 5.1 Technology choice

First, we compare the technology choice with and without the environmentalists' participation. We have shown before that $k_G^*$ is a U-shaped with respect to $z$. Further, $k_{NG}^*$ is not a function of $z$. The following proposition compares $k_G^*$ and $k_{NG}^*$ and shows that $k_G^* > k_{NG}^*$ for one range of values of $z$ for each pair $(a, \gamma)$.

**Proposition 4:** *For each pair of values* $(a, \gamma)$*, there is a critical value of* $z$*,* $z_l$ *beyond which* $k_G^* > k_{NG}^*$.

Proposition 4 shows that the participation of the environmentalists will lead to higher permit prices than in they were not participating. This will lead to the two effects discussed above: Technology substitution (higher permit prices make the cleaner technology relatively cheaper) and output reduction (firms produce less because the increase in the price of permits implies an increase in their marginal cost of production). As $z$ increases, the second effect becomes stronger reducing the incentives to invest on "cleaner" technologies. It follows that there is a value of $z$ $(z_l)$ which is high enough to induce the adoption of a more polluting technology than the one that would be adopted in the absence of the environmentalists. Below this value of $z$, the participation of the environmentalists will lead to the adoption of cleaner technologies.

We can illustrate the above result with a numerical example. Recall that the technological choice (in the absence of the environmentalists) depends on $a$ and $\gamma$. Take the case of $a = 1.5$ and $\gamma = 1$, the technology choice when the environmentalists are absent from the ETS yields $k^*_{NG} = 0.830$. Interestingly, the presence of the environmental group would render more polluting technology choices ($k$ higher than 0.830) for $z > 1.286$.

## 5.2 Output and Emissions

Here, we compare the equilibrium levels of output and emissions across the two cases (with and without the environmentalits' participation in the ETS). First, it is important to notice that for a given $k$, firms produce more in the absence of the environmentalists. This also leads to a higher level of emissions by the two firms purchasing permits. The following remark explains.

**Lemma 3** $\sum_{i=1}^{2} q^*_{i,G} < \sum_{i=1}^{2} q^*_{i,NG}$ *and* $\sum_{i=1}^{2} y^*_{i,G} < \sum_{i=1}^{2} y^*_{i,G}$ *for a given* $k$.

However, as the participation of the environmentalists' in the permits market will influence firms' technological choice, it is necessary to go beyond the analysis of output and emissions levels for given values of $k$. In the previous section, we have shown that firms will choose a more polluting technology in the presence of the environmentalists than in their absence for high values of $z$ ($z > z_l$). As a consequence of this, and given that the equilibrium output levels are decreasing in $k$, we can state the following.

**Proposition 5:** *The comparison of the cases with and without the environmentalists participation yields the following results,*

i) $k^*_G \leq k^*_{NG}$ and $\sum_{i=1}^{2} q^*_{i,G} \lesseqqgtr \sum_{i=1}^{2} q^*_{i,NG}$ if $z \leq z_l$.

ii) $k^*_G > k^*_{NG}$ and $\sum_{i=1}^{2} q^*_{i,G} < \sum_{i=1}^{2} q^*_{i,NG}$ *if* $z > z_l$.

Proposition 5 states that the participation of environmental groups in the ETS can induce firms to adopt less polluting technologies and even reduce their output levels as long as the environmentalists are not too impurely altruistic. However, if the environmentalists are characterised by sufficiently high degrees of impure altruism, firms will choose a manufacturing technology which is more polluting than the one they would choose in the absence of the environmentalists.

This last observation (proposition 5.ii) does not imply that the emissions levels by firms $i$ and $j$ would actually increase if environmentalists characterised by high degrees of impure altruism participated in the ETS. In fact, proposition 5.ii emphasizes the existence of a trade-off between the technology choice and the level of output for higher degrees of impure altruism. Interestingly, firms $i$ and $j$'s emissions levels decrease despite the use of more polluting technologies due to the lower levels of production. We can use some numerical examples to illustrate this. Let us assume that $a = 1$ and $\gamma = 1$; in such a case, the equilibrium technology choice in the absence of the environmentalists is $k^*_{NG} = 0.933$ and each firm's output ($q^*_{i,G}$) and emissions ($y^*_{i,G}$) are respectively 0.216 and 0.203. Now assume that the environmentalists are characterised by a (relatively) high degree of impure altruism, for example, $z = 1.1$ (in this case, $z_l = 0.577$). In such a case, the equilibrium technology choice is more polluting ($k^*_G = 0.985$) but individual emissions are lower ($y^*_{i,G} = 0.022$). The reason for this is that the two firms adjust their output level downwards (individual output in this case is 0.022), resulting in a lower emissions level by each firm.

# 6 Conclusions

In this paper we examined the participation of environmental groups in the Emissions Trading System (ETS) and its effects on firms' technological choices. We have analyzed the case where there are two firms in the tradable permits market which are acting as duopsonists in the product market and can choose their manufacturing technologies among a continuum of technologies which differ in their associated emissions per unit of output and their set-up costs. We have assumed that "greener" technologies (lower emissions per unit of output) are more expensive to adopt. In the spirit of Andreoni (1989, 1990), we have also considered that the environmentalists are impurely altruistic; that is, they decide on the number of permits to withdraw partly driven by their own utility gains (*warm glow*).

We show that firms purchasing permits in the ETS tend to produce less the more polluting their production technology is and that large market sizes and low technology costs favour the adoption of less polluting technologies, both with and without the environmentalists' presence in the ETS. Furthermore, firms' decisions on output levels are strategic interdependent even when firms do not compete in the final output market.

Our results also show that there is a U-shape relationship between how polluting the chosen technologies are and the degree of impure altruism. Interestingly, the participation of the environmentalists in the ETS can induce the adoption of production technologies which are "greener" than they would be in the absence of the environmentalists. This requires that the environmental group are characterized by not too high degrees of impure altruism. In fact, for high degrees of impure altruism the presence of the environmental group in the ETS could actually induce firms to adopt a more polluting (non-green) technology but also to produce less output (and emissions). For lower degrees of impure altruism, the participation of the environmentalists would lead to the adoption of less polluting technologies and in some circumnstances to lower output levels too.

We have conducted a number of checks to test the robustness of our results to changes in the objective function of the environmental group. In particular, including consumer or (even) producer welfare into the objective function of the environmentalists does not affect qualitatively any of them.

Therefore, one can conclude that it is far from clear that the participation of third parties in ETS will necessarily induce technological improvements. Further research would be certainly welcome in the topic of this paper. In particular, it would be worthwhile to allow for various forms of competition in the final product market.

# 7 References


1. Ahlheim, M., and Schneider, F. 2002. "Allowing for household preferences in emission trading," Environmental and Resource Economics, 21: 317 – 342.

2. Andreoni, J. 1989. "Giving with impure altruism: Applications to charity and Ricardian equivalence," Journal of Political Economy, 97: 1447 – 1458.

3. Andreoni, J. 1990. "Impure altruism and donations to public goods: A theory of warm-glow-giving," Economic Journal, 100: 464 – 477.

4. Boyd, J., and Conley, J. 1997. "Fundamental nonconvexities in Arrovian markets and a Coasian solution to the problem of externalities," Journal of Economic Theory, 72: 388 – 407.

5. Chakravorty, U., Roumasset, J., and Tse, K. 1997. "Endogenous substitution among energy resources and global warming," Journal of Political Economy, 105: 1201 – 1234.

6. Coase, R. 1960. "The Problem of social cost," Journal of Law and Economics, 3: 1 – 44.

7. Conley, J., and Smith, S. 2005. "Coasian equilibrium," Journal of Mathematical Economics, 41: 687 – 704.

8. Dales, J. H. 1968. "Pollution, property and prices," Toronto: University of Toronto Press.

9. English, D., and Yates, A. 2007. "Citizens' demand for permits and Kwerel's incentive compatible mechanism for pollution control," Economics Bulletin, 17: 1 – 9.

10. Eshel, D. M. D., and Sexton, J. R. 2009. “Allowing communities to trade in imperfectly competitive pollution-permit markets,” Journal of Regulatory Economics, 36: 60 – 82.

11. Fischer, C., Parry, I. W. H., and Pizer, W. A. 2003. “Instrument choice for environmental protection when technological innovation is endogenous,” Journal of Environmental Economics and Management, 45: 523 – 545.

12. Goeree, J.K., Holt, C.A. and Laury, S.K, 2002, "Private costs and public benefits: unraveling the effects of altruism and noisy behavior", Journal of Public Economics, 83: 255 – 276.

13. Goulder, L. H., and Mathai, K. 2000. “Optimal CO2 abatement in the presence of induced technological change,” Journal of Environmental Economics and Management, 39: 1 – 38.

14. Goulder, L. H., and Schneider, S. H. 1999. “Induced technological change and the attractiveness of CO2 abatement policies,” Resource and Energy Economics, 21: 211 – 253.

15. Israel, D. 2007. “Environmental participation in the U.S. sulphur allowance auctions,” Environmental and Resource Economics, 38: 373 – 390.

16. Joskow, P. L., Schmalensee, R., and Bailey, E. M. 1998. “The market for sulfur dioxide emissions,” American Economic Review, 88: 669 – 685.

17. Kerr, S., and Newell, R. G. 2003. “Policy-induced technology adoption: Evidence from the U.S. lead phasedown,” Journal of Industrial Economics, LI: 317 –343.

18. Malueg, D. A., and Yates, A. J. 2006. “Citizen participation in pollution permit markets,” Journal of Environmental Economics and Management, 51: 205 – 217.

19. Newbery, D. M. 2008. “Climate change policy and its effect on market power in the gas market,” Journal of the European Economic Association, 6: 727 – 751.

20. Newell, R. G., Jaffe, A. B., and Stavins, R. N. 1999. “The induced innovation hypothesis and energy-saving technological change,” Quarterly Journal of Economics, 114: 941 – 975.

21. Palfrey, T.R., and Prisbey, J.E., 1996, "Altruism, Reputation and Noise in Linear Public Goods Experiments", Journal of Public Economics, 61: 409 – 427.

22. Palfrey, T.R., and Prisbey, J.E., 1997, "nomalous Behavior in Public Goods Expermients: How Much and Why", American Economic Review, 87: 829 – 847.

23. Popp, D. 2002. “Induced innovation and energy prices,” American Economic Review, 92: 160 – 180.

24. Requate, T., and Unold, W. 2003. “Environmental policy incentives to adopt advanced abatement technology: Will the true ranking please stand up?,” European Economic Review, 47: 125 – 146.

25. Rousse, O. 2008. “Environmental and economic benefits resulting from citizens’ participation in CO2 emissions trading: An efficient alternative solution to the voluntary compensation of CO2 emissions,” Energy Policy, 36: 388 – 397.

26. Schwarze, R., and Zapfel, P. 2000. “Sulfur allowance trading and the regional clean air incentives market: a comparative design analysis of

two major cap-and-trade permit programs?," Environmental and Resource Economics, 17: 279 – 298.

27. Shrestha, R. 1998. "Uncertainty and the choice of policy instruments: A note On Baumol and Oates propositions," Environmental and Resource Economics, 12: 497 – 505.

28. Smith, C. S., and Yates, J. A. 2003a. "Optimal pollution permit endowments in markets with endogenous emissions," Journal of Environmental Economics and Management, 46: 425 – 445.

29. Smith, C. S., and Yates, J. A. 2003b. "Should consumers be priced out of pollution-permit markets?," Journal of Economic Education, 34: 181 – 189.

30. United Nations. 1998. "Kyoto protocol to the united nations framework convention on climate change."

# 8 Appendix

## 8.1 Lemma 1

**Proof.** It is immediate to see that the denominator in (12) is positive. Therefore, the sign of $\frac{\partial q^*_{i,NG}}{\partial k_i}$ is determined by the sign of the numerator in (12). Given that $k_i, k_j \in (0,1)$,both $k_j(4(1+k_j^2)+k_i^2(4+3k_j^2))$ and $2k_i(4+3k_j^2)((2-k_ik_j+2k_j^2)))$ are positive. As $a>0$, the numerator in (12) is negative. As a consequence, we know that $\frac{\partial q^*_{i,NG}}{\partial k_i}<0$. ■

## 8.2 Proposition 1

**Proof.** The FOC implies $\frac{\partial \pi_{i,NG}}{\partial k_i}=0$. Using the implicit function we know that:

$$\frac{\partial k^*_{i,NG}}{\partial a}=-\frac{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial a}}{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial k_i}} \text{ and } \frac{\partial k^*_{i,NG}}{\partial \gamma}=-\frac{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial \gamma}}{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial k_i}}\ , \tag{a.1}$$

or rearranging,

$$\frac{\partial k^*_{i,NG}}{\partial a}=-\frac{\frac{\partial \pi_{i,NG}}{\partial k_i \partial a}}{\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}} \text{ and } \frac{\partial k^*_{i,NG}}{\partial \gamma}=-\frac{\frac{\partial \pi_{i,NG}}{\partial k_i \partial \gamma}}{\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}}. \tag{a.2}$$

We focus on the combinations of parameters that make the SOC hold (see footnote 13). This implies that $\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}$ in (a.2) is negative. Thus, it is easy to see that $\frac{\partial k^*_{i,NG}}{\partial a}$ and $\frac{\partial k^*_{i,NG}}{\partial \gamma}$ have respectively the same signs as $\frac{\partial \pi_{i,NG}}{\partial k_i \partial a}$ and $\frac{\partial \pi_{i,NG}}{\partial k_i \partial \gamma}$. Next, we must check the signs of $\frac{\partial \pi_{i,NG}}{\partial k_i \partial a}$ and $\frac{\partial \pi_{i,NG}}{\partial k_i \partial \gamma}$.

After calculating $\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial a}$, we substitute $k_i$ and $k_j$ by $k$. This yields $\frac{\partial \pi_{i,NG}}{\partial k_i \partial a}$ in symmetry, which is positive for any $k \in (0,1)$

$$\left.\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial a}\right|_{k_i=k_j=k}=\frac{-4ak(6+11k^2+6k^4)}{(2+k^2)(2+3k^2)^3}<0. \tag{a.3}$$

On the other hand, $\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial \gamma}$ is obviously positive

$$\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial \gamma} = 2(1 - k_i). \tag{a.4}$$

We therefore know that $\frac{\partial k^*_{i,NG}}{\partial a} < 0$ and $\frac{\partial k^*_{i,NG}}{\partial \gamma} > 0$. Therefore, $k^*_{i,NG}$ is decreasing in $a$ and increasing in $\gamma$. ■

## 8.3 Proposition 2

**Proof.** It is immediate to see that $\frac{\partial x^{*;}_{G,S}}{\partial a} = \frac{-2k}{2(2+k^2)} < 0$, $\frac{\partial x^{*}_{G,S}}{\partial z} = \frac{(2+3k^2)}{2(2+k^2)} > 0$ for any $k \in (0,1)$. In words, $x^{*;}_{G,S}$ is decreasing in $a$ and increasing in $z$. Solving $x^*_{G,S} = 0$ for $a$ yields a critical value $a^{cv} = \frac{2k^2+2z+3k^2z}{2k}$, above which $x^*_{G,S} < 0$. This critical value is increasing in $z$. The rest of the proposition follows. ■

## 8.4 Lemma 2

$\frac{\partial q^*_{i,G}}{\partial k}$ evaluated in symmetry can be written as $\frac{\partial q^*_{i,G}}{\partial k} = -\frac{2k^2(8+6k^2-3k^3)+\delta_1-\delta_2}{2(4+8k^2+3k^4)^2}$, where $\delta_1 = ak(28+52k^2+27k^4)$ and $\delta_2 = z(8+20k^2+6k^4-9k^6)$ . Given that $k$ lies within the interval $(0,1)$, it is easy to see that $t_2 > 0$, and therefore $(t_1 + t_2) > 0$. As a consequence, $\frac{\partial q^*_{i,G}}{\partial k} < 0$.

## 8.5 Proposition 3

**Proof.** Using the implicit function theorem, the slope of the function $k^*_i(z)$ is given by $\frac{\partial k^*_i}{\partial z} = -\frac{\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}}{\frac{\partial^2 \pi_{i,G}}{\partial k_i^2}}$. Focusing on the case where $a$, $\gamma$ and $z$ take values that guarantee that the SOC for a maximum is met, $\frac{\partial^2 \pi_{i,G}}{\partial k_i^2} < 0$. Therefore, the sign of $\frac{\partial k^*_i}{\partial z}$ depends on the sign of $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$: If it is positive (negative), then

$\frac{\partial k_i^*}{\partial z} > (<)0$. After calculating $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$ , we substitute $k_i$ and $k_j$ by $k$, yielding

$$\left.\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}\right|_{k_i=k_j=k} = \frac{a\Gamma + z\Psi + \Lambda}{2(2+k^2)^3(2+3k^2)^2}, \tag{a.5}$$

where $\Gamma = (-16 - 52k^2 - 52k^4 - k^6 + 15k^8)$, $\Psi = 16k + 72k^3 + 108k^5 + 54k^7$ and $\Lambda = 24k^3 + 60k^5 + 40k^7$. It is easy to check that the denominator of $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$ $> 0$ and therefore, the sign of $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$ depends only on its of the numerator. Further, it is easy to check that $\Gamma < 0$; $\Psi > 0$ and $\Lambda > 0$ for any $k \in (0, 1)$. Solving the equation $a\Gamma + z\Psi + \Lambda = 0$, we can find the critical value of $z$, $z_{cv}$ above (below) which $\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial z}$ is positive (negative). As a consequence, if $z >$ $(<)$ $z_{cv}$, $\frac{\partial k_i^*}{\partial z} > (<)0$. This critical value is $z_{cv} = \frac{-\Lambda - a\Gamma}{\Psi}$. As $\Gamma < 0$, it is easy to check that $\frac{\partial z_{cv}}{\partial a} > 0$, therefore, the critical value is increasing in $a$. ■

## 8.6 Proposition 4

**Proof.** From Proposition 3 we know that there is a critical value of $z$, $z_{cv}$, above (below) which $k_G^*$ is decreasing (increasing). Further, we know that $k_{NG}^*$ does not depend on $z$, that is, it is constant with respect to $z$. It follows from the functional forms of $k_G^*$ and $k_{NG}^*$ with respect to $z$ that there 3 possible cases: i) $k_G^*$ and $k_{NG}^*$ cross once (in the increasing part of $k_G^*$) of , ii) $k_G^*$ and $k_{NG}^*$ cross twice (once in the increasing and once in the decreasing part of $k_G^*$) or iii) $k_G^*$ is strictly higher than $k_{NG}^*$ in the feasible range of $z$, $z > 0$.The critical value $z_l$ will be the value of $z$ at which $k_G^*$ and $k_{NG}^*$ cross in the increasing part of $k_G^*$ (cases i and ii) or $z = 0$ (case iii). Thus, if $z > z_l$, $k_G^* > k_{NG}^*$. ■

## 8.7 Lemma 3

**Proof.** We know that the equilibrium output will be higher if $x = 0$ than is if $x > 0$, given that $\frac{\partial q_i^*}{\partial x} < 0$. The output level for $x = 0$ is equivalent ot the output level in the absence of the environmentalists. It follows that $q_{i,G}^{*} < q_{i,NG}^{*}$. Further, recall that the emissions levels in market $i$ are given by $y_i = k_i q_i$. Thus, for a given $k$, higher output implies higher emissions. The rest of the lemma follows. ■

## 8.8 Proposition 5

**Proof.** It follows from the functional forms of $k_G^{*}$, $k_{NG}^{*}$ and lemmata 1, 2 and 3. ■